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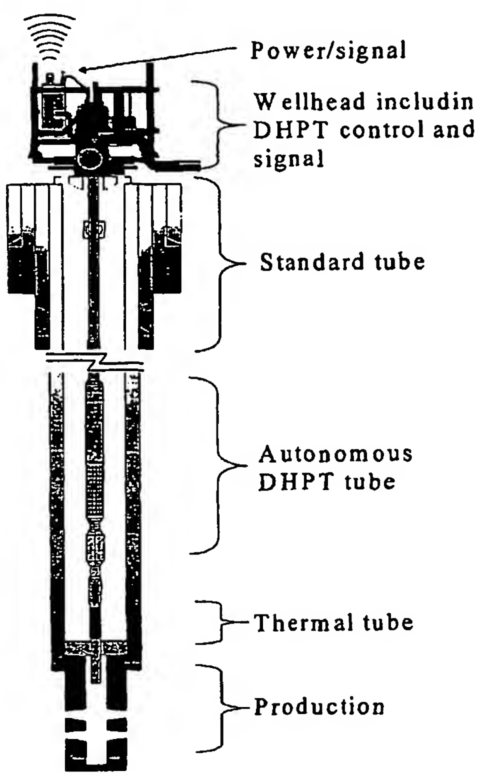
[Continued on next page]

(54) Title: AUTONOMOUS DOWNHOLE/RESERVOIR MONITORING AND DATA TRANSFER SYSTEM



(57) Abstract: The system described is an autonomous downhole monitoring system for wells. The autonomous downhole monitoring system is integrated with conventional production tubing and installed without the need of topside control such as power supply or communication cables in the well, thus making the system autonomous. The system can be installed in wells with conventional conditions as well as in high pressure and in high temperature locations. Power generation is achieved locally downhole and electrical power is stored in an incorporated battery bank. Communication between the monitoring system and the topside is achieved by means of acoustic transducers and receivers.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Autonomous Downhole/Reservoir Monitoring and Data Transfer System

The invention relates in general to a system for measuring physical parameters in pipes, preferably downhole measuring in wells, and more specifically to a system where power generation and communication takes place independently of the presence of cables, thus forming an autonomous system. The system is suitable for operations in a variety of wells.

According to authority regulations the operators are obliged to maximize the field recovery rate upon a field development project. In order to achieve this requirement, reservoir management is partially obtained by installing downhole gauges for continuous monitoring of reservoir parameters. During the last years, it has become mandatory to include downhole gauges in completed subsea wells. However, conventional design including a cable strapped to the downhole pipe string has proven to have too high failure rate compared to the expectations. In addition, installation costs have proven to be unexpectedly high, due to extensive use of rig time. Fields with high pressure and temperature add on an extra high risk factor. Though downhole gauges to monitor wells already exist on the market, their use still represents a major expenditure for oil companies due to high losses. Systems available in the market require electrical supply and communication lines running the length of the downhole pipe from the wellhead down to the downhole gauge, usually secured by using clamps fitted onto the tubing. Fitting cables to the tubing is a time consuming activity that greatly lengthen the installation time compared with tubing installation without downhole gauges. During the installation of traditional gauges, the cables and clamps are greatly exposed and can easily be damaged, thus having the highest rate of failure. If damage occurs, the worst case scenario is that the entire length of tubing must be retrieved to replace a damaged cable. If the damage equipment is repairable downhole, a wire line operation must be performed.

Communication using acoustics has proved feasible and is used, but still requires the use of some sort of power supply for permanent systems. By introducing an autonomous downhole reservoir/well parameter monitoring system, reservoir management goals can be achieved at a low risk. The risk level of installing and introducing an autonomous downhole monitoring system is significantly lower than installation of a standard monitoring system with cables.

Oil fields, such as Statoil's Kristin subsea field characterized by high temperature and high pressure, having reservoir temperature exceeding 170°C and reservoir pressure exceeding 900 bar representing an extreme environment, requires

extensive preventive actions to be taken. One of these preventive actions is to develop and install a downhole monitoring system that eliminates the challenge of getting an electrical cable and cable clamps safely installed. Malfunctioning control lines and stuck cable clamps is a scenario that can be avoided, by introducing a downhole monitoring system according to the invention.
A complete autonomous system for measuring physical parameters like pressure and temperature in the production phase is not to be found on the market, neither is it suggested in the literature. The invention is thus dedicated to a complete working system suitable for use in surroundings with high temperature and pressure.

US-3,970,877 describes how power can be generated by using mud in the return flow. This technology does not correspond to this patent, and it can not be utilized in a system according to the invention, since the annulus has no flow, but is stagnant. The invention is dedicated to downhole measurement of completed wells. This implies that the only flow conditions present are inside the downhole pipe. In US-3,970,877, power generation is based on a piezo-electrical element bonded to a membrane which vibrates in a turbulent flow. Use of this type of power generation with the present invention would not be acceptable since the membrane would have to be exposed to production flow inside the downhole pipe, i.e. penetration of downhole pipe.

US-6,253,847 describes downhole power generation by using seawater in a battery. This is achieved by using the annulus side of the production string as a cathode, a dissimilar metal as anode and the annulus fluid as an electrolyte. The method is undesirable due to exposure to corrosion in the pipe element. The system according to the invention, in one embodiment, uses zinc anode and a silver-chloride cathode, where both elements are placed on the piping, and isolated from the pipe itself.
US-application 2000/0040379 describes electrical power generation based on vibrations through the use of fluid flow inside production tubing which induces electricity through the use of a piezo-electrical or a magnetic restrictive element. Vibration is obtained by choking the fluid flow.

The permanent autonomous system according to the invention is a downhole monitoring system that enables monitoring of downhole parameters such as pressure and temperature in both the reservoir and annulus bore, without the need of external power supply or communication cables from topside to the seabed. Energy needed to monitor and communicate with the topside is generated locally and excess energy produced is stored in high temperature batteries.
Communication is achieved by use of acoustic waves, using the production pipe

and/or annulus as signal conductor. The system is arranged such that it interfaces a standard element of a complete production string.

As mentioned, conventional gauges are equipped with cables strapped from the tubing string to the downhole gauge, and the cables supplies the power needed to monitor parameters like pressure and temperature in wells. The autonomous downhole monitoring system is integrated with conventional downhole pipe and installed without the need of topside control such as power supply or communication cables in the well, thus making the system autonomous. By making the monitoring system autonomous, the power has to be produced and accumulated down in the well. The system can be installed in wells with conventional conditions as well as in locations with high pressure and temperature. Electrical power generated locally is stored in an incorporated battery bank. Communication between the monitoring system and topside is achieved by means of acoustic transducers and receivers. Power generation is achieved by means of Peltier elements, Venturi or turbines, Isotopes, Linear generators etc.
The autonomous downhole monitoring system can typically monitor the following well parameters: production and annulus pressure, production and annulus temperature, sand erosion, corrosion, flow measurements and multi phase flow measurements.
The system with gauges and related equipment will be mounted onto a tubing element that can be fitted onto the rest of the tubing string in conventional methods. There will be no penetration of the tubing element (between well stream and annulus).
In order to obtain a system with redundancy, two or more generators based on different principles can be coupled in series. Since each autonomous tube element will integrate seamlessly with existing tube elements, the system is flexible and expandable.

In one embodiment, power is generated downhole in a thermoelectric system, utilizing the existing temperature difference between the annulus and the well fluid. Peltier elements attached to the outside of the tubing are used for converting the temperature difference into electrical power. As an alternative/supplementary power source, a system for conversion of applied pressure variations in the annulus into electrical power can be introduced. Chemical power generation using seawater batteries is also feasible. This principle is especially useful during the installation phase.

The main objective of the proposed system is to make it autonomous, excluding the cable strapped to the downhole pipe string.

The permanent autonomous monitoring according to the invention differs from existing systems by the following features: installation, safety, life span, cost savings, communication and power generation.

The monitoring system comprises a single element with standard tubing interface, resulting in a simple and time-effective installation, since the system does not require any cabling to be routed along the tubing to the seabed equipment.

The system is developed to serve and function in an extreme environment such as high temperature and pressure subsea completed wells where the safety requirements are high and downhole operations risky. Current downhole monitoring systems have generally short lifespan, thus requiring replacement that can be considered as a hazardous work and leading to high costs due to rig operations. The monitoring system is developed to be installed without hazardous situations caused by cable repair and loss of clamping equipment into the well and minimize well penetrations and to eliminate penetrations in the tubing hanger, i.e. between the annulus and the seabed equipment.

The system is designed to have a lifespan equal to the reservoir production time (5-10 years). Current systems have proven to be less reliable than expected and often stopped functioning before being taken into use.

Due to the fact that the system is designed as part of a stand-alone element, the interfacing standard tubing, no additional rig time is needed, offering operators considerable cost savings.

The communication is achieved by means of acoustic signalling between the downhole system and seabed equipment without the use of electrical conductors.

The permanent autonomous monitoring system utilizes several methods of power generation to ensure that power generation is achieved throughout its lifespan. Power generation is produced locally by means of: chemical electrical energy, thermo-electrical energy, pressure electrical energy. Power accumulation is achieved by means of re-chargeable, high temperature batteries.
The invention shall now be described with reference to the accompanying drawings in which:
Figure 1 shows an example of an autonomous downhole monitoring layout with the autonomous system installed in a standard downhole pipe.
Figure 2 shows a cross section of a pipe assembly.

Figure 3 shows a pipe element with Peltier and magnetostrictive (Terfenol-D) elements installed.

Figure 4 shows an example of a radioisotope thermoelectric generator.

Figure 5 shows a pressure-electric power generator element.

Figure 6 shows a production string with the autonomous system installed. In this embodiment, two generators based on different principles are coupled in series to obtain redundancy.

Figure 7 shows a downhole pipe with three major reflections along the tubing.

Figure 8 shows a block diagram of the electronics used in the autonomous system.

It is now referred to figure 1. This figure shows the system with a gauge assembly integrated and installed as part of a conventional tubing element. The autonomous tube element consists of components for power generation, power accumulation and signal transmission through tubing and/or annulus, and different measuring sensors like pressure and temperature sensors. The autonomous element provides a pressure containing barrier without any penetration between the annulus and production fluid. The signaling from the monitoring system to the platform control room is achieved by means of a dedicated ROV retrievable control module installed on the subsea tree. As a base case, the only system requirement is utilizing one electrical pair in the main umbilical, using communication on power.

Figure 2 and 3 show a cross section of a typical tubing joint integrated as part of a conventional tubing element. The element comprises different types of sensors for measurement of different physical parameters in the well flow and annulus. All the necessary electronics is located in the tubing joint. Parameters to be measured can be pressure, temperature, erosion, corrosion, and flow characteristics including multiphase flow. The components for storing energy are typically batteries and/or capacitors. These are charged by a thermo-electrical power generating system like Peltier elements as shown in the figure. Other energy generating systems can be pressure-electrical elements, chemical-electrical elements, elements with power generated due to mechanical vibrations, turbine, venturi and/or radioisotope thermoelectric generators. Signal transmission is obtained by applying acoustic signals longitudinally in the pipe and/or annulus fluid from the monitoring system element to the subsea tree. In this example, a magnetostrictive material (example: Terfenol) is used as the signaling actuator, however other suitable magnetostrictive materials may be used. In order to obtain redundancy, several elements with different components for generating energy based on different principles can be coupled in series.

Figure 4 shows one type of power generating element based on isotopes. Systems using this energy source have no moving parts and have proven extreme reliability. Radioisotope thermoelectric generators (RTGs) currently designed for space

missions contain several kilograms of an isotopic mixture of the radioactive element plutonium 238 or the less dangerous Tritium in the form of an oxide, pressed into a ceramic pellet. The pellets are arranged in a converter housing where they function as a heat source to generate the electricity provided by the RTG. The natural radioactive decay of the isotope produces heat (RTGs do not use fission or fusion), some of which is converted into electricity by an array of thermocouples made of silicon-germanium junctions. An RTG uses no moving parts to create electricity.

Figure 5 shows another type of power generating element that may be used in the autonomous system. The pressure-electric power generation is a well known principle. In the majority of subsea wells, it is possible to pressure up the annulus. The energy represented by the ΔP can be transformed and stored downhole by various methods. To ensure that other fluids do not contaminate the annulus fluid, a dedicated annulus fluid supply line to the subsea tree should be designed and included. The size of the supply line is dependent on the available time interval for each pressure cycling and the required ΔP. The fact that subsidence and potential casing collapse is a concern in fields with high pressure makes active annulus pressure monitoring a necessity. Harmonic pressure pulsations can be generated using a hydraulic or a pneumatic device. The most simple is a hydraulic piston or displacement pump driven from a power source at the surface. Again, these are well documented and reliable devices.

Figure 6 shows an autonomous system with two generators based on different principles, and coupled in series to obtain redundancy. Since each autonomous tube element will integrate seamlessly with existing tube elements, the system according to the invention is flexible and expandable.

In one embodiment, power is generated downhole in a thermoelectric system, utilizing temperature difference between the annulus and well fluid. Peltier elements attached to the outside of the tubing are used for converting the temperature difference into electrical power. As an alternative/supplementary power source, a system for conversion of applied pressure variations in the annulus into electrical power can be introduced. Chemical power generation using seawater batteries is also feasible.

Figure 7 shows a downhole pipe with three major reflections along the tubing. Signal transmission through the tubing is the preferred method for communication. Reflections will occur in each cross section, and changes in cross sections should be avoided. As the total system also makes up a periodic structure, one should also

be aware of pass and stop band effects. The first stop band might be expected around 200Hz, with one half wavelength between the junctions. Pre-filtering of the received signal is performed as simple frequency filters. Cross correlation and inverse filtering of reflection models is performed for further signal refinements.

Figure 8 shows a block diagram of the electronics used in the autonomous system. The proposed system according to the invention is designed to be used at any location, included a high pressure and temperature one, like the Kristin field. The evolution in high temperature electronics has been significant in the recent years. The preferred electronics used in a system according to the invention is the HTMOS series from Honeywell combined with Asics from Sintef, integrated in a single package. Products form these suppliers are commercially available, and rated for temperature beyond 200°C. The energy consumption requirement is an important input to the energy generation. It can be divided into 3 major sections: sleep, monitoring/measuring and transmission.

During sleep, the only energy needed is related to keeping the electronics alive and capable to be woken up/activated on internal or external events. The processor core can be kept sleeping, and woken up every hour and perform a set of measurements, and then put to sleep again. The disadvantage is that an unexpected event, like an unprovoked shutdown is hard to catch. The typical current consumption for the circuit is outlined below. The current consumption in the table below represents the running mode.

Device	Current [mA]	Power [mW]
HT 6256 SRAM	6	30
HT 83C51 @ 1MHz	20	100
Oscillator	6	50
LPELS and Xtal	15	75
Total	47	255

The current consumption is relatively high compared to newer generation electronics, but the electronics is carefully selected based on reliability figures only.

During transmission, the power consumption is calculated to approx 10W, which is mainly used by the magnetostrictive actuator. Due to this fact, the energy for transmission mode has to be accumulated over time, and transmission of data is only performed occasionally. The overall energy consumption of the system is set to 350mW, including energy accumulation.

During the installation phase a battery package is required in order to diagnostic the system. This battery package may utilize seawater in the annulus as the catalyst between a zinc anode and a silver-chloride cathode, with both elements placed on the piping, and isolated from the pipe itself.
As primary energy source during normal production, a thermo-electrical generation is selected, due to the well delta temperature. This principle is well known and proven in the field. The main obstacle in this case, is a small temperature gradient, which however can be compensated by using a large area, and extending the temperature gradient artificially.

As a secondary power generating source, a pressure-electrical system is preferred. This system converts the static pressure built up in the annulus into electrical energy. This involves moving parts, buy they are moving slowly and are hermetically sealed. Generators built on these principles have shown lifecycle times up to 10 years.

As mentioned, Peltier elements are used for the thermoelectric power generation. These electrical devices were originally produced to act as an electrical cooler. When a Peltier element is exposed to a voltage, the elements get warm on one side, and cold on the other. This effect can also be reversed. When a Peltier element is subjected to a thermal difference a voltage is generated. This reverse effect is called the Seebeck effect. The main challenge for downhole thermo- electrical systems, in addition to the surroundings, is creating the temperature gradient/heat flux over the elements. The main reason for the equalization between the tubing and annulus is that the heat flux is dominated by flow in the tubing. The simplest and best solution is to force the heat flow through the Peltier elements, concentrating the temperature gradient to the thermocouples. In addition the section before the gauge/thermocouples can be expanded later or concentrated before, giving compression to the flow, and thereby extending the temperature gradient further. None of these measures will have any impact on well intervention or the installation.

Conversion of the fluid oscillations to electrical energy can be done using a linear generator using electromagnetic or magnetostrictive (Terfenol) elements. To extract sufficient energy, this should be a resonance device tuned to oscillate at the same frequency as the fluid. Considerable development is currently being carried out on linear generators for free piston engines, and for a small generator a motion of a few millimeters should be sufficient for the invention described herein.

Another solution is to use static pressure, built up over and over again. The static pressure is built up and transferred into a accumulator device, mechanical or hydraulic. This energy is converted over time to electrical energy, by a linear generator. The generator part has shown efficiency up to 90% at 50 Hz.

Power transmission through acoustic generation from the surface to charge the downhole instrumentation battery pack during periods of non-production from the well is a major development task. The most promising method is acoustic energy propagation through the pipe wall. To achieve sufficient energy transfer, the pipe wall or annulus fluid must be excited with longitudinal waves at a resonance frequency. This will require a tunable feedback control system, since the resonance frequency is a function of pipe length and fluid characteristics such as temperature. The frequency must be tuned to give maximum dynamic amplitude at the required location. Factors affecting choice of frequency are the frequency response of excitation and receiver systems, attenuation of transmitted energy, interference with the communication system, and frequency content of background noise sources. Selection of exciter and receiver locations is also of great importance to maximize the response. Due to the fact that attenuation increases proportional to frequency, it is likely that low frequency transmission in the range 0-300Hz will be most beneficial for wells located at large depths. Several attempts have been done to make signal transducers for acoustic communication. One of the most recent attempts is described in US patent application US-605255, using a stack of ceramic discs encapsulated in metal tubing [Drumhelle, Douglas – Sandia Labs]. This was done to overcome the weaknesses of crystals, and to improve the impedance match between the tubing and the transducer. Due to evolutions in material technology new transducers are possible, using magnetostrictive materials like Terfenol. When exposed to a magnetic field, Terfenol changes properties, and expands, mainly in the length axis. By designing a transducer with this material, it is possible to get near perfect impedance match, i.e. good coupling, by choosing the correct l/d ratio. The transducer is also subjected to preloaded stress, to get maximum force and coupling from the transducer.

Energy and hence signals can be transferred through a solid material. Use of acoustic propagation along cylindrical tubes is known. The technique is standard wave propagation, and is mainly a function of the material and frequency used. The main disturbances in such systems are reflections and noise. Main wave modes are: shear/transversal, torsional and longitudinal waves.
Shear waves may be excited by forces normal to the tubing wall. Propagation speed is independent of frequency, but dependent on materials (propagation is approx.

3000m/s for steel). Generally, the attenuation due to structural losses is proportional to frequency (app. 10dB/km for 10KHz). Attenuation due to radiation losses is proportional to f^3, i.e. the use of higher frequencies should be avoided for this mode. Regarded as added mass, joints will create reflections. Propagating through bends, shear waves will partially be converted to torsion waves. Transmission losses are bigger with smaller curvature radii. Torsional waves have wave velocities as shear waves, and structural losses in the same range as both shear and longitudinal waves. Radiation losses are only 30% of those of longitudinal waves. Torsional waves are partially converted to flexural waves in bends and joints and these may be greater than for shear- and longitudinal waves. Few mechanical noise sources will perform as torsional waves. Longitudinal waves may be excited by forces longitudinal to tubing. Using steel parameters, the phase speed is: $C_{phase} \approx$ 5000m/s (close to independent of frequency), and the mechanical loss is : $10^{-3} f$ dB/km.

The transverse contraction caused by longitudinal waves will result in sound radiation to the surrounding medium. An approximate expression for attenuation due to radiation to a free field using steel and water parameters is:

$\alpha_{lw} \approx 2.5 \ 10^{-3} \ f^2 \ d^2$ dB/km where d is the diameter of the tube.

The connection between tube sections will cause mechanical damping as well as reflections. Although reflection and transmission coefficients may be calculated, the total and exact response will have to be found experimentally.

There are several different physical methods to prevent unwanted reflections and degraded transmission. From the reflection and transmission coefficients it is obvious that changes in cross section should be avoided (permanent changes are "worst case"). As the total system also makes up a periodic structure, one should also be aware of pass and stop band effects. The first stop band might be expected around 200Hz, with one half wavelength between junctions.

Figure 7 shows a total transmission system with three major reflection points along the wave path. These are inserted for demonstration purposes and do not necessarily correspond to real completion strings. The different waves interfere with each other (constructively or destructively). In addition, topside noise is added. Cross correlation processing is used to give an indication of the information left in the original signal. The modeling and the simulation can be performed with MATLAB/SIMULINK and may be a valuable tool for adjusting the system for specific requirements.

The topside receiver is a listening device. Since the temperature topside is “normal”, the receiver section can be made up of more standard units. As receiver element, microphones, piezo-elements, magnetostrictive (Terfenol) and several other solutions are possible. High sensitivity listening devices are common, and used in gas leak detection, and cracking of metals. In addition a powerful electronic analyzing tool must be applied, in order to extract the data signal from the noise floor by applying advanced signal processing like correlation, integration etc. Standard DSP’s can be used for this application.

The downhole monitoring assembly shall be installed as an integrated part of the completion string and positioned just above the production packer. Detailed operating and handling instructions must be issued prior to offshore installation. The fact that there is no cable eliminates the most critical installation sequences of conventional monitoring systems.
The downhole assembly can be transported offshore in a standard 12 meter basket. The assembly will be positioned 1-5 tubing joint above the production packer.

During the installation phase the energy is drawn from the battery package. This may utilize seawater, a zinc anode and a silver-chloride cathode to produce energy. Both elements are placed on the piping, but isolated from the pipe itself. The monitoring system is set in installation mode by exposing it to specific external stimuli, like seawater. During the installation phase, the data-transmission system is triggered cyclically in order to monitor, and adjust, the carrier characteristics. The following parameters are suggested monitored during the installation phase: temperature in annulus and tubing, pressure in annulus and tubing, Shock Power generation status flags, temperature difference over the thermo-electrical generator and accumulator status. After a preset time the monitoring system leaves the installation phase and enters the continuous diagnostic mode.

Claims:

1. A system for measuring, storing and transmitting physical parameters in a pipe or a fluid, preferably in a well and especially a production well, comprising means for:
   - generating energy;
   - accumulating and storing energy;
   - controlling generation and storage of energy,

   characterized in that the system is autonomous and comprises means for:
   - measuring the physical parameters;
   - measuring the physical parameters at predetermined intervals;
   - sending the signals from downhole to a receiver by using a magnetostrictive material generating acoustic waves propagating in the pipe and/or in the fluid.

2. A system according to claim 1, where the means for generating energy are thermo-electrical elements, pressure-electrical elements, chemical-electrical elements, mechanical vibration generating power elements, fluid flow generated power elements or radioisotope thermoelectric generators.

3. A system according to claim 1, where the means for storing energy are high temperature rechargeable batteries and/or capacitors.

4. A system according to claim 1, where the physical parameters are pressure, temperature, erosion, corrosion, and flow characteristics including multiphase flow sensors.

5. A system according to claim 1, where the receiver means for the signals comprise microphones, piezo-electric and/or magnetostrictive elements.

6. A system according to claim 1, where the pipe can be located in a high temperature and pressure environment.

7. A system according to claim 1, where the measuring is performed both in the installation phase and in a phase with normal flow in the pipe.

8. A system according to claim 2, where the thermo-electrical elements are Peltier elements.

9. A system according to claim 4, where the measured pressure and temperature are the production and annulus pressure and the temperature in a drill pipe.

10. A system according to claim 1, 2, or 3, where the means for generating energy, components for storing energy and components for sending signals are all integrated in a single pipe element.

11. A system according to claim 10, where several pipe elements are placed in series to obtain redundancy.

12. A system according to claim 10, where several different means for generating energy based on different principles are coupled in series.

13. A system according to claim 7 and 10, with a first energy generating element operable in the installation phase being based on the chemical-electrical principle, and a second energy generating element operable under normal flow conditions preferably being a thermo-electrical element, pressure-electrical element and/or fluid flow generated power element.

14. A system according to claim 13, where the element based on the chemical-electrical principle is set to activation mode when it is exposed to specific external stimuli.

15. A system according to claim 13, where the elements leave the installation phase and enter a continuous diagnostic mode after a predetermined time.

16. A system according to claim 13, where the element operable in the installation phase can comprise a seawater battery with a zinc anode and a silver-chloride cathode, where both elements are placed on, and isolated from the pipe.

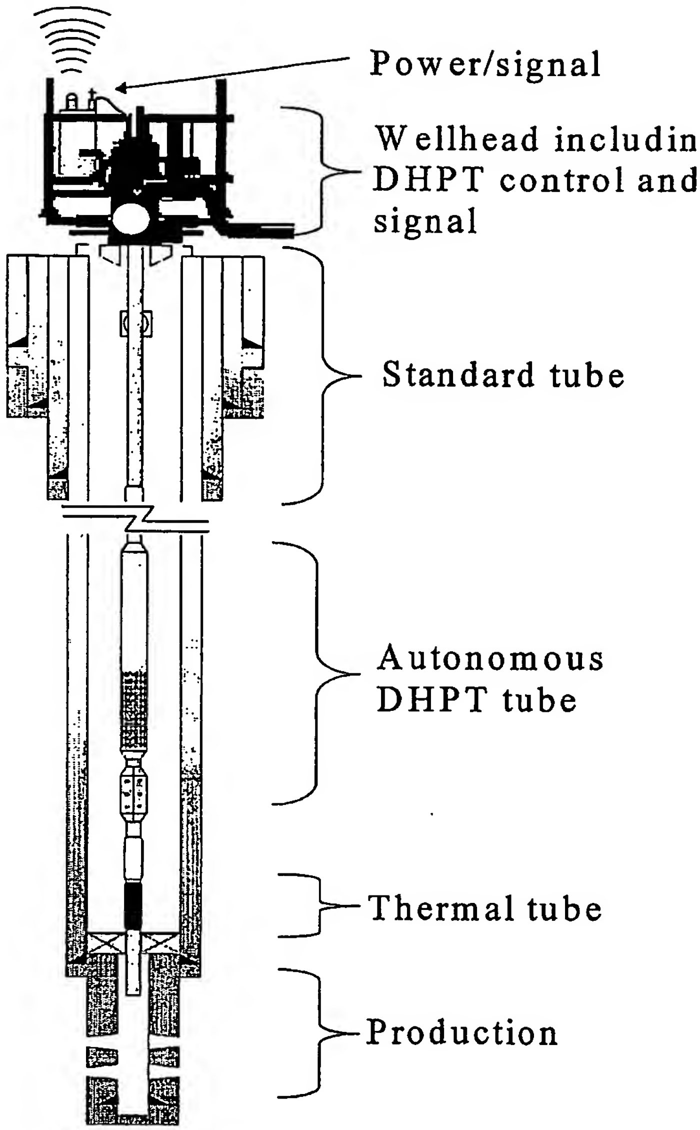

Power/signal
Wellhead includin DHPT control and signal
Standard tube
Autonomous DHPT tube
Thermal tube
Production

Fig. 1

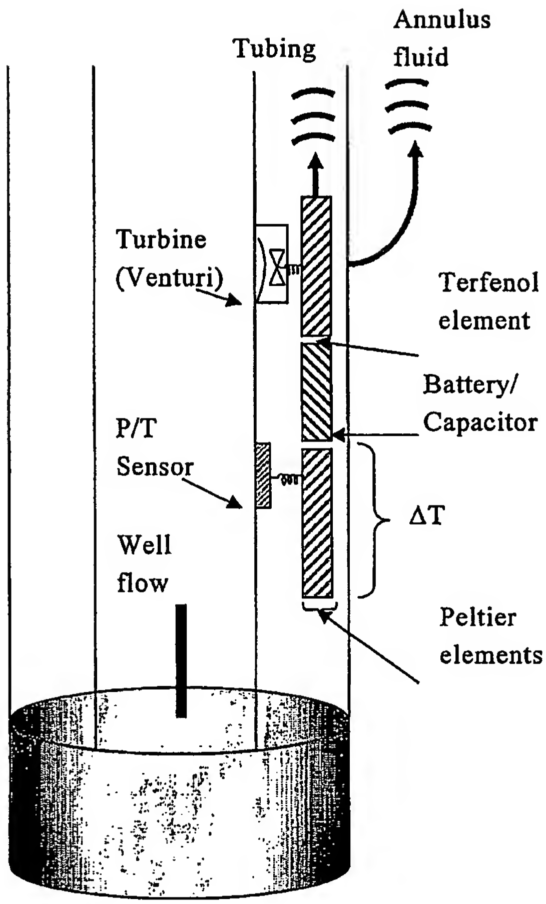

Annulus
fluid
Tubing
Turbine
(Venturi)
Terfenol
element
Battery/
Capacitor
P/T
Sensor
ΔT
Well
flow
Peltier
elements

Fig. 2

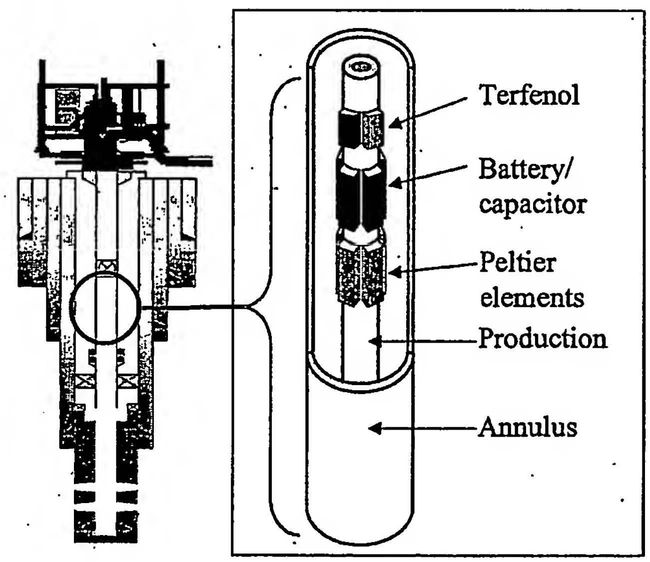

Terfenol
Battery/
capacitor
Peltier
elements
Production
Annulus

Fig. 3

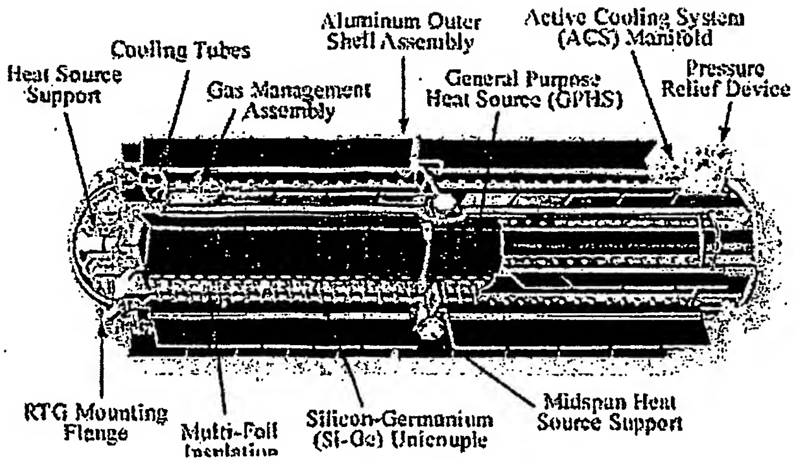
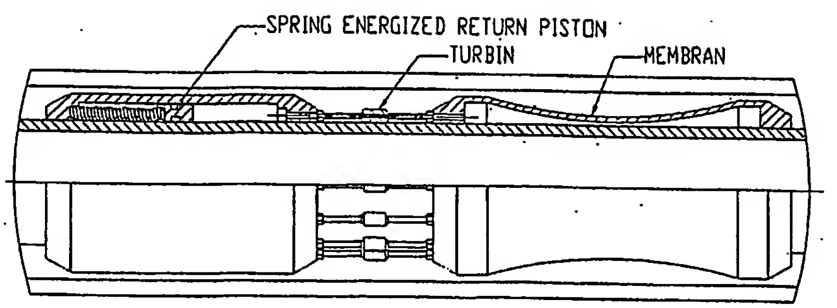


Fig. 4



(J) PRESSURE ELECTRICAL GENERATION

Fig. 5

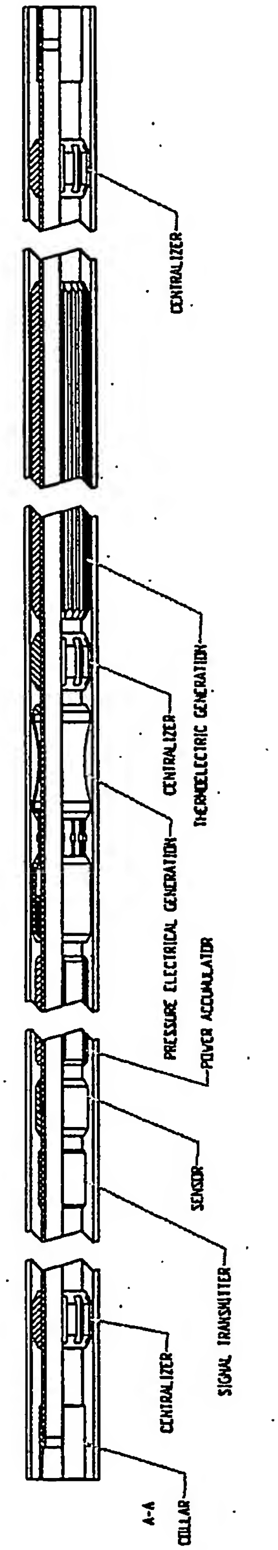

CENTRALIZER
THERMOELECTRIC GENERATION
CENTRALIZER
PRESSURE ELECTRICAL GENERATION
POWER ACCUMULATOR
SENSOR
SIGNAL TRANSMITTER
CENTRALIZER
A-A
COLLAR

Fig. 6

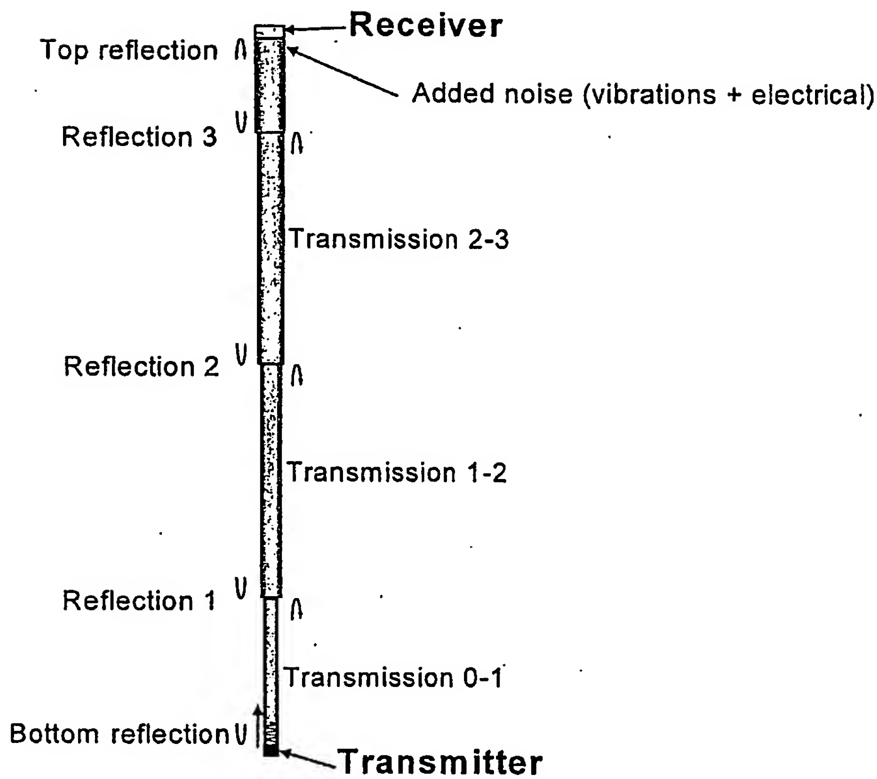

Receiver
Top reflection
Added noise (vibrations + electrical)
Reflection 3
Transmission 2-3
Reflection 2
Transmission 1-2
Reflection 1
Transmission 0-1
Bottom reflection
Transmitter

Fig. 7

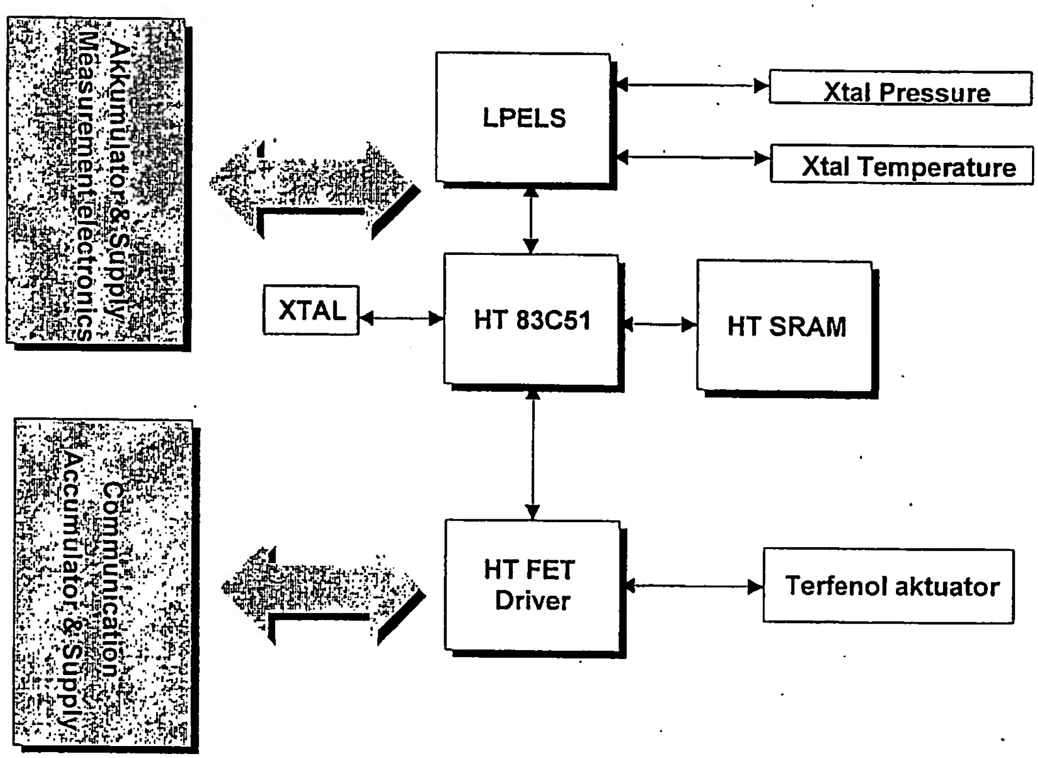

Akkumulator & Supply
Measurement electronics
Communication
Accumulator & Supply
LPELS
Xtal Pressure
Xtal Temperature
XTAL
HT 83C51
HT SRAM
HT FET
Driver
Terfenol aktuator

Fig. 8

INTERNATIONAL SEARCH REPORT

....rnational Application No
PCT/NO 03/00051

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B47/00 E21B47/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 615 172 A (KOTLYAR OLEG M) 25 March 1997 (1997-03-25) claims	1-5,9
A	US 3 233 674 A (KURT LEUTWYLER) 8 February 1966 (1966-02-08) the whole document	1-16
A	WO 98 12418 A (INTELLIGENT INSPECTION CORP CO) 26 March 1998 (1998-03-26) the whole document	1-16
A	WO 98 02634 A (SCHLUMBERGER CA LTD ;SCHLUMBERGER SERVICES PETROL (FR); JARDINE ST) 22 January 1998 (1998-01-22) the whole document	1-16

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 May 2003	22.05.2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	CHRISTER BÄCKNERT/JA A

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/NO 03/00051

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